

## Prof. Dr. Nihat Ay

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Research Group Leader  
*Information Theory of Cognitive Systems*  
Max Planck Institute for Mathematics in the Sciences  
Inselstraße 22, D-04103 Leipzig, Germany  
Phone: +49 - (0)341 - 9959 - 547  
Fax: +49 - (0)341 - 9959 - 555  
Email: [nay@mis.mpg.de](mailto:nay@mis.mpg.de)  
Homepage: <http://www.mis.mpg.de/ay/>

Honorary Professor  
Department of Mathematics and  
Computer Science, University of Leipzig

Professor  
Santa Fe Institute  
1399 Hyde Park Road  
Santa Fe, NM 87501, USA

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## Curriculum Vitae

### Personal Data

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<i>Name</i>	Nihat Ay
<i>Date of Birth</i>	March 2, 1970
<i>Place of Birth</i>	Antakya, Turkey
<i>Marital Status</i>	Married, three children
<i>Citizenship</i>	German

### Main Research Interests

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- Complexity and information theory
- Mathematical theory of learning in the context of neural networks, cognitive systems, and robotics
- Graphical models (Bayesian networks) and their applications to causality theory
- Information geometry and its applications to biology
- Geometric structures in quantum information theory

### Education

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4/2009	Habilitation (Dr. rer. nat. habil.), Department Mathematik, Friedrich Alexander University Erlangen-Nuremberg. Habilitation thesis: <i>Multi-Information as Guiding Scheme for Complexity Theory</i> .
2/2001	Ph.D., Mathematics (Dr. rer. nat.), University of Leipzig. Dissertation (in German): <i>Aspects of a Theory of Pragmatic Information Structuring</i> .
1997–2000	Ph.D. Student, Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany. Subject: <i>Mathematical Aspects of Neural Networks</i> . Advisor: Jürgen Jost
1989–1996	Study of Mathematics and Physics, Ruhr University Bochum, Bochum, Germany. Diploma Thesis (in German): <i>A Combinatorial Geometric Approach to the Hopfield Model</i> .

## Scientific Experience

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<i>Since 3/2014</i>	Part-time resident Professor, Santa Fe Institute, Santa Fe, New Mexico, USA.
<i>Since 9/2005</i>	Leader of Max Planck Research Group ( <i>Information Theory of Cognitive Systems</i> ), Max Planck Institute for Mathematics in the Sciences (W2-Position, permanent since March 2013).
<i>7/2004–8/2004</i>	Guest Researcher at the Redwood Center for Theoretical Neuroscience, UC Berkeley, California, USA.
<i>9/2003–6/2004</i>	Postdoctoral Fellow, Santa Fe Institute.
<i>5/2003–8/2005</i>	Scientific Member (assistant professor level C1), Institute of Mathematics, Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany.
<i>4/2002–5/2002</i>	Guest Researcher at Shun-ichi Amari's Mathematical Neuroscience Laboratory, Brain Science Institute, RIKEN, Wako-shi, Japan.
<i>7/2000–4/2003</i>	Staff Researcher, Max Planck Institute for Mathematics in the Sciences.
<i>1/1997–6/2000</i>	Ph.D. Student, Max Planck Institute for Mathematics in the Sciences.
<i>1992–1996</i>	Graduate Student Instructor, Mathematical Department, Ruhr University Bochum.

## Honors and Awards

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<i>Since 2/2015</i>	Honorary Associate and steering committee member of <i>The International Association for Guided Self-Organisation</i> at The University of Sydney.
<i>Since 12/2013</i>	Honorary Professor for Information Geometry, Department of Mathematics and Computer Science, University of Leipzig.
<i>9/2009–11/2013</i>	Associate Professor (Privatdozent) for Mathematics, Department of Mathematics and Computer Science, University of Leipzig.
<i>3/2005–2/2014</i>	External Professor, Santa Fe Institute.
<i>5/2000</i>	Schloßmann Award for Research on Mathematical Modeling in Biology, Chemistry, and Physics.
<i>12/1996</i>	ATIAD (Society of Turkish Entrepreneurs and Industrialists in Europe) Award for Diploma Thesis.

## Affiliations and Memberships

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<i>Since 11/2012</i>	<i>American Mathematical Society</i> . (AMS)
<i>Since 5/2009</i>	<i>2nd &amp; 3rd European Network for the Advancement of Artificial Cognitive Systems, Interaction and Robotics</i> (EUCogII & III).
<i>3/2007–12/2008</i>	<i>The European Network for the Advancement of Artificial Cognitive Systems</i> (eu-Cognition).
<i>Since 3/2007</i>	<i>Complex Systems Society</i> .
<i>10/2006–12/2012</i>	<i>Top-Level Research Area Mathematical Sciences</i> , University of Leipzig.
<i>Since 9/2005</i>	International Max Planck Research School (IMPRS) <i>Mathematics in the Sciences</i> at the University of Leipzig.
<i>5/2002–9/2006</i>	ZiF-Network of Young Researchers, The Center for Interdisciplinary Research (ZiF), University of Bielefeld, Bielefeld, Germany.

## Third Party Funds

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- 2015–2017 *An information-theoretic approach to autonomous learning of embodied agents.* Second phase of the below-listed DFG project within the Priority Program (Schwerpunktprogramm) *Autonomous Learning*. 246.200 €.
- 2012–2015 *Mathematics of Multilevel Anticipatory Complex Systems (MatheMACS).* Collaborative Project of the European Union within the Seventh Framework Program. Consortium members: MPI MIS, Universität Bielefeld, Chalmers University of Technology (Sweden), Inria (France), Ca’Foscari University of Venice (Italy), Università Politecnica delle Marche (Ancona, Italy). 1.531.750 €.
- 2012–2014 *An information-theoretic approach to autonomous learning of embodied agents.* A DFG project within the Priority Program (Schwerpunktprogramm) *Autonomous Learning*. Together with Eckehard Olbrich. 450.400 €.
- 2011–2013 *Evolution of Networks: Modeling the complexity and robustness of evolving biochemical networks.* Volkswagen Foundation (VW) project, together with Jürgen Jost (MPI MIS), Konstantin Klemm (University of Leipzig), Eckehard Olbrich (MPI MIS), and Peter Stadler (University of Leipzig). This project is an extension of the VW project below based on a positive evaluation. 555.000 €.
- 4/2007–6/2010 *Evolution of Networks: Robustness, Complexity, and Adaptability.* VW project, together with Jürgen Jost, Konstantin Klemm, and Peter Stadler. 497.400 €.
- 9/2004–3/2008 *Entropy, Geometry, and Coding of Large Quantum Information Systems.* German Research Foundation (DFG) project, together with Andreas Knauf (Erlangen), Burkhard Kümmeler (Darmstadt), and Ruedi Seiler (Berlin). 183.200 €.
- 10/2008–11/2008 DFG Scholarship within the DFG-MoE collaboration agreement with China; guest researcher at MPI MIS: WU Yaokun, associate professor at Shanghai Jiao Tong University, Department of Mathematics, Shanghai, China. 2.100 €.

## Teaching

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### Courses

1. *Geometric Aspects of Graphical Models and Neural Networks*, with Guido Motúfar, winter term 2014/2015, MPI MIS and University of Leipzig.
2. *Information Theory II*, summer term 2013, MPI MIS and University of Leipzig.
3. *Information Theory I*, winter term 2012/2013, MPI MIS and University of Leipzig.
4. *Graphical and Hierarchical Models*, part of the IMPRS-Ringvorlesung *Calculus in High-Dimensional Spaces*, winter term 2011/2012, MPI MIS and University of Leipzig.
5. *Stochastic Processes*, winter term 2010/2011, University of Leipzig.
6. *Discrete Optimization and Complexity*, winter term 2010/2011, University of Applied Sciences, Leipzig (HfTL, as guest lecturer).
7. *Stochastic Differential Equations*, summer term 2010 at University of Leipzig.
8. *Mathematical Learning Theory and Neural Networks*, summer term 2009, MPI MIS.
9. *Graphical Models and Causality*, summer term 2006, University of Leipzig.
10. *Information Geometry*, summer term 2005, Friedrich Alexander University Erlangen-Nuremberg.

## Seminars

1. *Model Selection I & II* (with Christian Haase, Alexander Schliep, and Thomas Kahle; summer term 2008 and winter term 2008/2009, MPI MIS).
2. *Concepts of Causality in Biology and Medicine* (with Korbinian Strimmer; summer term 2007, University of Leipzig).
3. *Classical Information Theory* (with Andreas Knauf; winter term 2004/2005, Friedrich Alexander University Erlangen-Nuremberg).

## Further Teaching Activities

1. Supervision and co-supervision of Ph.D. students at MPI MIS.
2. Teaching assistant at Ruhr University Bochum and Friedrich Alexander University Erlangen-Nuremberg: Introduction to Probability Theory, Probability Theory I & II, Mathematics for Biologists I & II, Calculus I & II, Algebra and Coding Theory.

## Organization of Workshops and Conferences

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1. *Fourth International Conference on Information Geometry and its Applications (IGAIA4)*, planned for mid 2016 at the Institute of Information Theory and Automation in Prague, with František Matúš.
2. *Causality in the language sciences: state-of-art methods from mathematics, statistics, and data science*, planned for 13-16 April, 2015, MPI MIS, with Damian Blasi, Jürgen Jost, Peter Stadler.
3. *Summer School on Autonomous Learning*, September 1-4, 2014, MPI MIS, with Marc Toussaint.
4. *Information Theory of Sensorimotor Loops*, October 8-10, 2013, Santa Fe Institute, with Friedrich T. Sommer.
5. *Conceptual and Mathematical Foundations of Embodied Intelligence*, February 27/28 & March 1, 2013, MPI for Mathematics in the Sciences (MPI MIS), with Ralf Der, Keyan Ghazi-Zahedi, Georg Martius.
6. *Perception & Action - An interdisciplinary approach to cognitive systems theory*, September 14-16, 2010, Santa Fe Institute, with Ray Guillery, Bruno Olshausen, Murray Sherman, Friedrich T. Sommer.
7. *Third International Conference on Information Geometry and its Applications (IGAIA3)*, August 2-6, 2010, MPI MIS, with Paolo Gibilisco and František Matúš (<http://www.mis.mpg.de/calendar/conferences/2010/infgeo.html>).
8. *The Second International Workshop on Guided Self-Organisation (GSO'09)*, MPI MIS (8/2009), with Ralf Der and Mikhail Prokopenko.
9. *Geometric Aspects of Conditional Independence and Information*, MPI MIS (3/2008), with František Matúš.
10. *Complexity and Information Theory*, MPI MIS (10/2007).
11. *Concepts of Intervention for System Identification and Robustness Studies*, MPI MIS (4/2007).
12. *Information Dynamics in Networks*, MPI MIS (10/2006).
13. *Geometry and Computation*, MPI MIS (1/2006).
14. *Geometry and Complexity in Information Theory*, Department Mathematik, Friedrich Alexander University Erlangen-Nuremberg (5/2005).
15. *Information Geometry*, MPI MIS (8/2003).

## Supervising Experience (Ph.D. Students)

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1. H. Bernigau. Ph.D. in Mathematics, University of Leipzig 2015: *Causal Models over Infinit Graphs and their Application to the Sensorimotor Loop – General Stochastic Aspects and Gradient Methods for Optimal Control*.
2. G. Montúfar. Ph.D. in Mathematics, University of Leipzig 2012: *On the Expressive Power of Discrete Mixture Models, Restricted Boltzmann Machines, and Deep Belief Networks - A Unified Mathematical Treatment*. Postdoctoral research associate at Penn State University and now member of my group.
3. J. Rauh. Ph.D. in Mathematics, University of Leipzig 2011: *Finding the Maximizers of the Information Divergence from an Exponential Family*. Winner of the Otto Hahn Medal of the Max Planck Society. Scientific assistant at the Institute of Algebraic Geometry, Leibniz University of Hannover.
4. T. Kahle. Ph.D. in Mathematics, University of Leipzig 2010: *(On Boundaries of Statistical Models*. Junior Professor at the Institute for Algebra and Geometry, Otto von Guericke University Magdeburg.
5. W. Löhr. Ph.D. in Mathematics, University of Leipzig 2010: *Generative Models of Stochastic Processes and Associated Complexity Measures*. Postdoctoral fellow at the Mathematics Department, University of Duisburg-Essen.
6. S. Weis. Ph.D. in Mathematics, University of Erlangen-Nuremberg 2009: *Exponential Families with Incompatible Statistics and Their Entropy Distance*. Co-supervision with Andreas Knauf.
7. I. Erb. Ph.D. in Mathematics, University of Leipzig 2002: *Wechselseitige Information im Thermodynamischen Limes*. Co-supervision with Jürgen Jost.

## Invited Talks

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### Talks at Conferences and Meetings

- *Workshop on Information Geometry for Machine Learning* (December 2014), Tokyo, Japan.
- *Workshop on Information Theory, Ecosystems, and Schrödinger's Paradox*. (November 2014), Santa Fe, NM, USA.
- *Information Geometry in Learning and Optimization (Ph.D. Course)* (September 2014), Copenhagen, Denmark.
- *Fifth International Workshop on Guided Self-Organisation (GSO)* (September 2012), Sydney, Australia.
- *Randomness, Structure, and Causality: Measures of complexity from theory to applications* (January 2011), Santa Fe, NM, USA.
- *Workshop on Graphical Models* (October, 2010), Heidelberg, Germany.
- *Long-term workshop: Mathematical Sciences and Their Applications* (September & October 2010), Nagano, Japan.
- *Third International Workshop on Guided Self-Organisation (GSO)* (September 2010), Bloomington, USA.
- *Symposium on Autonomous Systems* (May, 2010), Stuttgart / Tübingen, Germany.
- *Workshop on Geometric and Algebraic Statistics 2* (April 2010), Warwick, England.
- *Conference on Future of Computational Biology* (2009), Berlin/Potsdam, Germany.
- *Machine learning approaches to statistical dependences and causality* (2009), Dagstuhl, Germany.

- *Model Selection Days* (2009), Prague, Czech Republic.
- *Annual Meeting of the German Physical Society (DPG 2009)*, Munich, Germany.
- *Algebraic Statistics* (2008), Berkeley, USA.
- *The First International Workshop on Guided Self-Organisation (GSO)* (2008), Sydney, Australia.
- *Information and Communication* (2008), Budapest, Hungary.
- *Think Tank in Systems Biology. Statistical Semantics of Genomes: From Sequence to Function* (2008), Évry, France.
- *Workshop on Statistical Complexity* (2008), Warwick, UK.
- *Workshop on Genetic and Biological Networks: Models, Dynamics, and Simulations (ECCS 2007)*, Dresden, Germany.
- *Emergent organisation in complex biomolecular systems (EMBio 2007)*, Leipzig, Germany.
- *Workshop on Networks in Computational Biology* (2006), Ankara, Turkey.
- *Self-Organization of Behavior in Robotic and Living Systems* (2005), Göttingen, Germany.
- *Encoding and Decoding of Biological Signals: From Genes to Grammars* (2005), Santa Fe, NM, USA.
- *Network: From Biology to Theory* (2005), Beijing, China.
- *Computational Neuroscience Conference (CNS 2002)*, Chicago, IL, USA.
- *Information Geometry and its Applications* (2002), Pescara, Italy.
- *Concepts for Complex Adaptive Systems* (2002), Delmenhorst, Germany.

#### External Seminar Talks

- Karlsruhe Institute of Technology (2015). TBA.
- MPI for Biological Cybernetics (2013). *On the role of mathematics within the field of embodied intelligence.*
- Santa Fe Institute (2013). *On the role of mathematics within the field of embodied intelligence.*
- Michigan State University (2013). *On the role of mathematics within the field of embodied intelligence.*
- Faculty of Mathematics. Chemnitz University of Technology (2012). *Eine geometrische Sicht auf den Begriff der Komplexität.*
- Faculty of Mathematics. Chemnitz University of Technology (2009). *An Information-Geometric Approach to Complexity of Composite Systems.*
- Institute of Mathematics. University of Erfurt (2009). *An Information-Geometric Approach to Complexity Theory.*
- Department Mathematics Institute. Santa Fe Institute (2009). *The Geometry of Information as Mathematical Framework for Biology.*
- Department Mathematics Institute. Friedrich Alexander University Erlangen-Nuremberg (2009). *The Geometry of Information as Mathematical Framework for Biology.*
- Redwood Center for Theoretical Neuroscience (2008). *Causality, Information Flows, and the Perception-Action Loop.*
- Department of Information and Computer Sciences. University of Hawaii (2008). *Information Maximization in Recurrent Structures.*
- Department of Computer Science. University of Hertfordshire (2008). *Causal Information Flows and the Common Cause Principle.*

- Gatsby Computational Neuroscience Unit. University College London (2008). *Towards an integration of infomax concepts.*
- Bristol Centre for Complexity Science (2008). *Statistical Complexity Measures.*
- Santa Fe Institute (2007). *A Quantitative Refinement of Reichenbach's Common Cause Principle.*
- Institute for Neuro- and Bioinformatics at the University of Lübeck (2007). *On the Concept of Information Flow.*
- Mathematical Department of the Johannes Gutenberg University Mainz (2007). *Relating Stochastic Dependence to Information Flows.*
- Mathematical Department of the Technical University Darmstadt (2006). *Interventional versus Observational Conditioning.*
- Santa Fe Institute (2005). *On Complexity Maximization in Cognitive Systems.*
- Mathematical Department of the Technical University Berlin (2004). *Computational Mechanics.*
- Mathematical Department of the Technical University Berlin (2004). *On Maximization of the Information Divergence from Exponential Family.*
- Santa Fe Institute (2004). Lecture series on *Information Geometry.*
- Institute of Information Theory and Automation (2002), Academy of Sciences of the Czech Republic, Prague, Czech Republic. *Information Geometry on Complexity and Infomax Principles.*
- Mathematical Neuroscience Laboratory (2002), Brain Science Institute, RIKEN. *Information Geometry on Complexity and Infomax Principles.*

## Review Activities

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- **Journals.** Algorithms for Molecular Biology, Communications in Theoretical Physics, PLoS Computational Biology, Discrete Applied Mathematics, Entropy, Neural Computation, Physical Review Letters, IEEE Transactions of Information Theory, Physical Review A, Physica A, Advances in Complex Systems, Kybernetika, Theory in Biosciences, Zeitschrift für Naturforschung A .
- **Program Committees.** Guided Self-Organization 1–7 (GSO 2008 – 2014), 9th & 12th Workshop on Uncertainty Processing (WUPES 2012 & 2015), International Joint Conference on Artificial Intelligence (IJCAI 2011), Australasian Workshop on Computation in Cyber-Physical Systems 1 & 2 (CompCPS-2010/11), 26th Conference on Uncertainty in Artificial Intelligence (UAI 2010), Information Theory and Statistical Learning (ITSL 2008), European Conference on Complex Systems (ECCS 2007), German Workshop on Artificial Life (GWAL 2008).
- **Grants.** Expert evaluator for the European Research Area Network (ERA-NET) *Complexity-Net* (2010), expert evaluator for the *Cognitive Systems, Interaction, and Robotics* program of the European Commission (ICT - Information and Communication Technologies), since 2007.
- **Ph.D. Programs.** Review of Ph.D. applications as Scientific Member of the International Max Planck Research School (IMPRS), review of applications for the Complex Systems Summer School organized by the Santa Fe Institute.
- **Postdoctoral Programs.** Review of applications for postdoctoral positions as Committee Member of the European Postdoctoral Institute (EPDI), review of applications within the postdoctoral program of the Santa Fe Institute, and also for the Max Planck Institute for Mathematics in the Sciences.

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## Publication List

### Peer-Reviewed Articles

1. N. Ay. *Geometric Design Principles for Brains of Embodied Agents*. Künstliche Intelligenz 2015, in press. Santa Fe Institute Working Paper 15-02-005.
2. N. Ay. *Information Geometry on Complexity and Stochastic Interaction*. Entropy (2015), in press.
3. B. Steudel, N. Ay. *Information-theoretic inference of common ancestors*. Entropy (2015), in press. arXiv:1010.5720.
4. S. Weis, A. Knauf, N. Ay, and M.-J. Zhao. *Maximizing the Information Divergence from a Hierarchical Model of Quantum States*. Open Systems and Information Dynamics (2015) 22 (1): 1550006. doi: 10.1142/S1230161215500067.
5. D. Krakauer, N. Bertschinger, E. Olbrich, N. Ay, J. Flack. *The Information Theory of Individuality*. In: L. Nyhart, S. Lidgard (eds.) *The Philosophy of Individuality*. University of Chicago Press 2014, in press.
6. O. Pfante, N. Ay. *Operator-theoretic identification of closed sub-systems of dynamical systems*. Discontinuity, Nonlinearity and Complexity (2015): 91–109. doi: 10.5890/DNC.2015.03.007.
7. N. Ay, J. Jost, H. V. Lê, L. Schwachhöfer. *Information geometry and sufficient statistics*. Probability Theory and Related Fields (2014). doi: 10.1007/s00440-014-0574-8.
8. G. Montúfar, J. Rauh, N. Ay. *Information Geometry of Polytopes*. Entropy (2014) 16(6): 3207–3233.
9. N. Bertschinger, J. Rauh, E. Olbrich, J. Jost, N. Ay. *Quantifying Unique Information*. Entropy (2014) 16(4): 2161–2183.
10. O. Pfante, E. Olbrich, N. Bertschinger, N. Ay, J. Jost. *Closure Measures and the Tent Map*. Chaos (2014) 24(1): 013136. doi: 10.1063/1.4869075.
11. O. Pfante, N. Bertschinger, E. Olbrich, N. Ay, J. Jost. *Comparison Between Different Methods of Level Identification*. Advances in Complex Systems 17 (2014) 1450007. doi: 10.1142/S0219525914500076.
12. P. Moritz, J. Reichardt, N. Ay. *Discriminating between causal structures in Bayesian Networks via partial observations*. Kybernetika 50(2) (2014) 284–295.



13. K. Zahedi, G. Martius, N. Ay. *Linear combination of one-step predictive information with an external reward in an episodic policy gradient setting: a critical analysis*. *Frontiers in Psychology* (2013). doi: 10.3389/fpsyg.2013.00801.
14. N. Ay, K. Zahedi. *On the Causal Structure of the Sensorimotor Loop*. In: M. Prokopenko (ed.) *Guided Self-Organization: Inception*. Springer 2014.
15. M. Prokopenko, D. Polani, N. Ay. *On the Cross-Disciplinary Nature of Guided Self-Organisation*. In: M. Prokopenko (ed.) *Guided Self-Organization: Inception*. Springer 2014.
16. J. Rauh, N. Ay. *Robustness, canalising functions, and systems design*. *Theory in Biosciences* (2013). doi: 10.1007/s12064-013-0186-3.
17. G. Martius, R. Der, N. Ay. *Information-driven self-organization: behavior as search*. *PLoS ONE* (2013) 8(5): e63400. doi:10.1371/journal.pone.0063400
18. G. Montúfar, J. Rauh, N. Ay. *Maximal Information Divergence from Statistical Models Defined by Neural Networks*. *Geometric Science of Information* 2013. arXiv:1303.0268.
19. K. Zahedi, N. Ay. *Quantifying Morphological Computation*. *Entropy* (2013) 15(5): 1887–1915. doi: 10.3390/e15051887
20. G. Lohmann, J. Stelzer, J. Neumann, N. Ay, R. Turner. “More is different” in fMRI: a review of recent data analysis techniques. *Brain Connectivity* (2013) 3(3): 223 – 239. doi:10.1089/brain.2012.0133.
21. P. Moritz, J. Reichardt, N. Ay. *A new common cause principle for Bayesian networks*. *Proceedings of WUPES’12* (2012) 149–162.
22. W. Löhr, A. Szkoła, N. Ay. *Process dimension of classical and non-commutative processes*. *Open Systems and Information Dynamics* 19 (1) (2012) 1250007.
23. N. Ay, E. Olbrich, N. Bertschinger, J. Jost. *A Geometric Approach to Complexity*. *Chaos* 21 (2011) 037103.
24. G. Montúfar, J. Rauh, N. Ay. *Expressive Power and Approximation Errors of Restricted Boltzmann Machines*. *Proceedings of NIPS* 2011.
25. N. Ay, G. Montúfar, J. Rauh. *Selection Criteria for Neuromanifolds of Stochastic Dynamics*. Post-conference proceedings *Advances in Cognitive Neurodynamics (III)*. Springer 2012.
26. N. Ay, K. Zahedi. *An Information-Theoretic Approach to Intention and Deliberative Decision-Making of Embodied Systems*. Post-conference proceedings *Advances in Cognitive Neurodynamics (III)*. Springer 2012.
27. N. Ay, W. Wenzel. *On Solution Sets of Information Inequalities*. *Kybernetika* 48 (2012) 5, 845–864.
28. N. Ay, M. Müller, A. Szkoła. *Effective Complexity of Stationary Process Realizations*. *Entropy* (2011) 1200–1211.
29. N. Ay, H. Bernigau, R. Der, M. Prokopenko. *Information driven self-organization: The dynamical system approach to autonomous robot behavior*. *Theory in Biosciences* (2011). doi 10.1007/s12064-011-0137-9.
30. J. Rauh, T. Kahle, N. Ay. *Support Sets in Exponential Families and Oriented Matroid Theory*. *International Journal of Approximate Reasoning* 52 (2011) 613–626.
31. G. Montúfar, N. Ay. *Refinements of Universal Approximation Results for Deep Belief Networks and Restricted Boltzmann Machines*. *Neural Computation* 23 (5) (2011) 1306–1319.

32. M. Prokopenko, N. Ay, O. Obst, D. Polani. *Phase transitions in least-effort communications*. Journal of Statistical Mechanics (2010) P11025.
33. K. Zahedi, N. Ay, R. Der. *Higher coordination with less control – A result of information maximisation in the sensori-motor loop*. Adaptive Behavior 18 (2010) 338–355.
34. E. Olbrich, T. Kahle, N. Bertschinger, N. Ay, J. Jost. *Quantifying structure in networks*. Eur. Phys. J. B 77 (2010) 239–247.
35. N. Ay, M. Müller, A. Szkoła. *Effective Complexity and its Relation to Logical Depth*. IEEE Transactions on Information Theory 56 (9) (2010) 4593–4607.
36. W. Löhr, N. Ay. *On the Generative Nature of Prediction*. Advances of Complex Systems 12 (2) (2009) 169–194.
37. D.C. Krakauer, J.C. Flack, N. Ay. *Probabilistic design principles for robust multimodal communication networks*. In: Modeling Perception with Artificial Neural Networks. Eds. G. Ruxton and C. Tosh. Cambridge University Press UK 2009.
38. T. Kahle, W. Wenzel, N. Ay. *Hierarchical Models, Marginal Polytopes, and Linear Codes*. Kybernetika 45 (2) (2009) 189–208.
39. W. Löhr, N. Ay. *Non-Sufficient Memories that are Sufficient for Prediction*. Proceedings of Complex’2009, Shanghai. Volume 4 (I) of LNICST (2009) 265–276.
40. T. Kahle, E. Olbrich, J. Jost, N. Ay. *Complexity Measures from Interaction Structures*. Phys. Rev. E 79, 026201 (2009).
41. N. Ay. *A Refinement of the Common Cause Principle*. Discrete Applied Mathematics 157 (2009) 2439–2457.
42. N. Ay, N. Bertschinger, R. Der, F. Güttler, E. Olbrich. *Predictive Information and Explorative Behavior of Autonomous Robots*. European Physical Journal B 63 (2008) 329–339.
43. R. Der, F. Güttler, N. Ay. *Predictive information and emergent cooperativity in a chain of mobile robots*. ALife XI Proceedings, MIT Press 2008.
44. E. Olbrich, N. Bertschinger, N. Ay, J. Jost. *How should complexity scale with system size?* European Physical Journal B 63 (2008) 407–415.
45. N. Ay, D. Polani. *Information Flows in Causal Networks*. Advances in Complex Systems 11 (1) (2008) 17–41.
46. N. Bertschinger, E. Olbrich, N. Ay, J. Jost. *Autonomy: an Information-Theoretic Perspective*. BioSystems 91 (2). Special issue: *Modelling Autonomy* (guest editors: X. Barandiaran, K. Ruiz-Mirazo) (2008) 331–345.
47. N. Ay, J.C. Flack, D.C. Krakauer. *Robustness and Complexity Co-constructed in Multi-modal Signaling Networks*. Philos Trans R Soc Lond B Biol Sci (2007) 441–7.
48. N. Ay, D.C. Krakauer. *Geometric Robustness Theory and Biological Networks*. Theory in Biosciences (2007) 93–121.
49. J. Jost, N. Bertschinger, E. Olbrich, N. Ay, S. Fraenkel. *An information-theoretic approach to system differentiation on the basis of statistical dependencies between subsystems*. Physica A 378 (2007) 1–10.
50. N. Ay, A. Knauf. *Maximizing Multi-Information*. Kybernetika 42 (5) (2007) 517–538.

51. T. Wennekers, N. Ay, P. Andras. *High-resolution multiple-unit EEG in cat auditory cortex reveals large spatio-temporal stochastic interactions*. *BioSystems* 89 (2007) 190–197.
52. T. Wennekers, N. Ay. *A Temporal learning rule in recurrent systems supports high spatio-temporal stochastic interactions*. *Neurocomputing* 69 (2006) 1199–1202.
53. N. Bertschinger, E. Olbrich, N. Ay, J. Jost. *Information and Closure in Systems Theory*. Proceedings of the 7th German Workshop on Artificial Life (2006).
54. N. Ay, E. Olbrich, N. Bertschinger, J. Jost. *A Unifying Framework for Complexity Measures of Finite Systems*. Proceedings of ECCS'06. Santa Fe Institute Working Paper 06-08-028.
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